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ARTERIAL GRAFTS

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". . . blood of man
That swift as quicksilver . . . courses through
The natural gates and alleys of the body."
Edward de Vere
(Hamlet)

WORLD War II, with its many vascular injuries, again focused surgical attention on the great need for a technique to bridge a defect in a major artery with preservation of the arterial blood flow. The rapid growth of the surgical treatment of congenital and acquired cardiovascular defects during the period immediately following the war provided a continuing impetus for the elaboration of such a technique. It is now fair to state that the technical aspects of this problem have been largely overcome, and a great variety of arterial lesions may now be successfully repaired with preservation of blood flow.

Among the variety of agents evolved for grafting an arterial defect are: (1) an autogenous vein, (2) an autogenous vein wrapped with fascia, (3) a highly polished plastic prosthesis, (4) an artificial tube of fibrous tissue (pericardium), (5) a formalin or alcohol fixed segment of homologous or heterologous artery, and (6) a cold-preserved or lyophilized segment of homologous artery. Although all of these methods have met with a considerable degree of success, the most practical method giving the most consistent and uniformly favorable results is the use of the preserved arterial homograft.

To Pierce, working in Gross's laboratory should go the credit for reintroducing the arterial graft. Although Carrel and Guthrie, at the turn of the century, had demonstrated experimentally the successful use of such grafts, clinical and experimental interest in the problem had remained dormant. Since 1948, however, many surgical laboratories across the country have been studying this method vigorously.

One of the major problems relating to the clinical use of the arterial homograft (transplantation of an arterial segment from a donor of the same species) is that of availability. The grafts must be obtained sterile from young individuals, from 2 to 35 years of age, previously in good health, who die a sudden or relatively acute death. The vessels must be obtained within 6 hours postmortem. Since these conditions involve relationships with the patient's relatives (permission), coroner's office (medicolegal aspects), and morticians (embalming), and since the time limitation is strict, the procurement of an adequate supply of segments for the "artery bank" is often difficult, even in large communities. The panel of eligible donors may be increased in communities where high voltage cathode ray irradiation, in the order of magnitude of 2.0 or 2.5 roentgen equivalent phys-

ical units delivered to frozen vessels, can be employed to sterilize segments obtained from unsterile autopsy material. Such machines, however, are not widespread.

The problem of storage is equally important. The fresh arterial segment, transplanted immediately after death of the donor, appears to be the most desirable graft and, barring technical mistakes, yields almost 100 per cent successful results. To preserve grafts for a long period in a condition which corresponds as closely as possible to the fresh state would appear to be the goal of the storage method. Preservation in a fluid medium consisting of a balanced salt solution containing 10 per cent plasma or serum in an icebox at 4 degrees C. accomplishes this aim for periods up to about 45 days. Gross found that tissue culture viability disappeared and the percentage of failures of aortic grafts increased rapidly after this period, although we have had successful experimental and clinical results up to 6 months of storage. This storage method therefore suffers the defect of being satisfactory for only a short period of time, thus requiring frequent replacement of a commodity hard to procure.

"Deep" freezing of arterial grafts has been shown to be successful in the experimental laboratory by Hufnagel and by Deterling. The former froze the grafts dry at −196 degrees C. (liquid nitrogen) and stored at −74 degrees C. (carbon dioxide); the latter froze dry at −74 degrees C. and stored at −27 degrees C. (commercial deep-freeze unit). Recently we have shown that vessels frozen rapidly at low temperatures, either −78 degrees C. or −196 degrees C., if frozen in nutrient media and thawed rapidly, retain their capacity to grow in tissue culture. Tissue culture studies also suggest that a low (−78 degrees C.) storage temperature is superior to that of the commercial deep freeze (−27 degrees C.). It seems probable that grafts may be kept almost indefinitely in a condition approximating the freshly obtained vessel if rapidly frozen in nutrient media at −78 degrees C. and stored at the same temperature. Recently, also, lyophilization has been suggested as a method of preservation. This technique has the merit of simplicity, of storage at room temperature, and of transportability of the graft. Much work remains to be done, however, to evaluate the consistency of success which may be expected from the use of lyophilized grafts.

Suture anastomosis is best suited for insertion of the graft. This may be done by temporarily controlling blood flow proximally and distally with noncrushing arterial clamps during the anastomoses; or, if preservation of blood flow during the procedure is essential, as for example in the carotid artery, the technique of "minimal interruption" over a temporarily placed polythene tube may be employed. All the niceties of technique of vascular suture—strict asepsis, avoidance of tissue injury by trauma or desiccation, careful stripping of the adventitia, careful placement of small atraumatic sutures, careful wound closure without dead space or necrosis—must be meticulously observed. In addition, the employment of a graft of proper size is of paramount importance. The lumen of the graft, when distended by the blood pressure, must match as exactly as possible the lumen of the recipient vessel, thus forming a vessel in continuity of uniform or tapering caliber. If either anastomosis forms a constriction, or if the graft distends, thus creating a sudden change in the size of the vessel, turbulence and eddy currents are created which strongly favor intraluminal thrombosis and failure. For the same reason, if a long graft is employed which must traverse a circuitous route, all curvatures should be gradual and no sharp

angulations permitted. If these precautions are observed, anticoagulant drugs need not be used, unless blood flow has been interrupted for a period of over an hour. If interruption has been prolonged, thrombosis of the distal arteries may occur, and heparin should be used to limit the spread of these distal thromboses.

The limitations on the size of artery suitable for grafting and the length of graft have not been clearly established. All arteries with an internal diameter of 3 millimeters or larger may be successfully grafted; it is probable that smaller ones may also be suitable but with less certain results because of technical difficulties. The maximum safe length for a graft is not certain, but relatively long ones (6 to 10 inches) have been used experimentally in the aorta of dogs. We have successfully transplanted clinically an aortic graft 5 inches and a femoral graft 3 inches long. It is possible that the length of graft which can be safely used may prove to be a function of its diameter.

The fate of these homografts is particularly interesting. All cellular elements in the graft are destroyed by host reaction by the end of the third week; the elastic tissue of the media, however, persists for a period of at least 2 years. An inflammatory reaction around the graft results, at 1 month, in a firm fibrous tissue outer layer. Meanwhile, the host is elaborating a new inner layer which grows in from each end of the graft, ultimately entirely lining it. At first primarily fibrocellular, this layer later undergoes remarkable differentiation; the inner cells assume endothelial forms and new elastic fibrils are laid down. Spotty or diffuse calcification may occur in this layer. Thus the host builds a new blood vessel on the scaffold of the elastic tissue of the graft.

The clinical potentialities of this technique are multiple. We have successfully used grafts in the treatment of the following lesions of arteries: coarctation of the aorta, mycotic aneurysm of the thoracic aorta, arteriovenous fistula (femoral), posttraumatic false aneurysm (femoral and axillary), acute traumatic injury (femoral), and malignant neoplasm invading an artery (femoral). In addition, Gross has used grafts to create shunts in cyanotic children when a suitable systemic artery was not available for anastomosis. Some arteriosclerotic aneurysms (ilial, innominate, lower aortic) may occasionally prove to be resectable. The implications to military medicine in the treatment of arterial battle injuries are obvious. The technique offers real promise in enlarging the scope of the operative attack on malignant disease in instances in which close proximity to or invasion of a vital artery by the neoplasm heretofore has precluded adequate resection. Arterial ligation which threatens loss of tissue distally or loss in function of an organ or extremity is, in the majority of instances, no longer justifiable in the treatment of arterial lesions.